

Genetic Algorithm Optimization of Inlet Bleeding Design for a Hypersonic Jet Engine with Mode Transition

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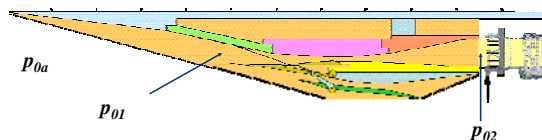
Background

Air-breathing engines rely on the surrounding air in the atmosphere to mix with the fuel carried on board. The inlet is the upstream engine component that directs the incoming air for combustion downstream. The inlet plays a crucial role in slowing down the air, with minimal losses, so that the air/fuel mixture and combustion has enough time to take place before it is propelled by the nozzle. Furthermore, the inlet is responsible for maintaining high stagnation pressure and uniform velocity and direction of the flow entering the compressor.

A high **pressure recovery** across in the inlet is critical to the engine's performance. Friction due to the inlet walls creates non-isentropic flow, slowing down the bordering air known as the boundary layer. Normally, shear forces (viscous and turbulent) keep the boundary layer from peeling off the wall. However, if there is a large, adverse pressure gradient across the inlet, **boundary layer separation** occurs, reversing flow and creating large pressure drag. The efficiency dramatically decreases and the engine stalls.

$$r_d = \frac{P_{02}}{P_{0a}}$$

P_{0a} is atmospheric stagnation pressure; P_{02} is downstream inlet stagnation pressure;
 P_{02} is upstream inlet stagnation pressure; r_d is pressure recovery



Supersonic inlets are more challenging to design, because **shock waves** occur at the inlet, which decrease engine performance. As the air slows down to subsonic conditions, pressure builds up until either a normal or oblique shock is released. Since normal shock loss is greater, the inlet is designed to swallow a series of oblique shocks, until one final, small normal shock brings the flow to subsonic conditions.

Taking into account these losses, a technique called **bleeding** is used to minimize boundary layer separation. Sections of the inlet wall are perforated; holes are deliberately engineered to allow the boundary layer air to escape. The holes are placed at sections where the oblique shocks strike the inlet wall, the area where separation would normally occur. Removing the low momentum air prevents boundary layer separation.

Hypersonic Mode Transition Engines

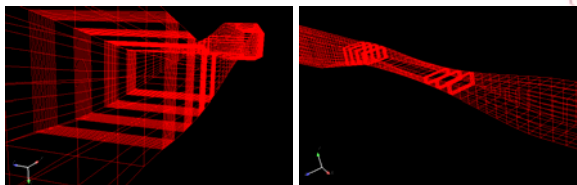
Hypersonic engines are a promising field of research for air and space vehicles. They will not only be the fastest aircraft, but they will transition between sub, super, and hypersonic modes, providing a single craft capable of the broadest array of speeds. When fully developed, hypersonic vehicles have the potential to become a single-stage escort to and from space.

Control of boundary layer separation is of utmost importance for these revolutionary mode transition inlets. Generally, inlets are designed differently for specific flight speeds, so engineering an inlet for a wide range of speeds with bleed controlled boundary layer separation, requires **innovative research and engineering techniques**.

Project

A genetic algorithm is written and applied to optimize the design of bleed holes in the walls of a hypersonic inlet. This is a **new** project, formed by the joint collaboration of the Engine Systems and the Inlet and Nozzle branches at NASA Glenn Research Center. From what is known, a genetic algorithm has never before been implemented for bleeding research.

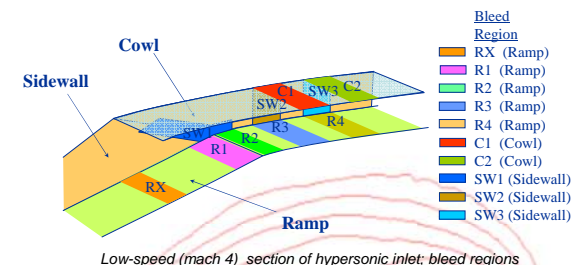
The genetic algorithm and grid generator are written in Fortran. The grid is created from a geometry adapted from a current hypersonic inlet design that is being tested in wind tunnels at NASA Glenn Research Center. The grid allocates more lines where holes are located, as shown below.



EnSight visualization of inlet from grid generator program

The genetic algorithm optimizes the pressure recovery of the inlet. The **alleles**, or design parameters, that change to optimize the inlet, are the **location** of each hole, the **diameter** of each hole, and the **mass flow rate** of air through each hole. The number of holes, and the range of each parameter's value is chosen and programmed into the code

ahead of time. Areas of possible bleeding are depicted below.



The genetic algorithm randomly chooses values for each parameter, creating an individual with one **chromosome**. Many individuals make a population. Overflow evaluates the inlet's performance under each individual's design and outputs the pressure values, from which an **objective function** in the genetic algorithm calculates the pressure recovery. Based upon the chromosome's pressure recovery, the objective function assigns it a fitness value.

The genetic algorithm uses the **roulette wheel** method to select the best fit parents for the next generation. **Crossover** and **mutation** operators vary the offspring. In this project, the mutation rate will likely be higher than most genetic algorithms because there are many possible combinations of parameters with large ranges to be considered. The process is repeated and after numerous generations, the design parameters with the best pressure recovery are returned.

What's Left To Do?

- Program overflow to dynamically change its script, allowing grid boundary conditions to adapt to each chromosome
- Extend genetic algorithm to create holes for upper and lower walls
- Write the objective function that assigns fitness values
- Run the genetic algorithm and interpret results

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